



Field trip analysis of the 39th Steering Committee CEM in the Cook Islands

By IUCN Commission on Ecosystem Management Steering Committee and CEM member Rob van der Weert



Following its CEM Steering Committee (SC) meeting in Rarotonga, Cook Islands, the SC made a field trip to the Island of Mangaia. The purpose of these field trips is to interact with local partners and gain ecosystem management experience at first hand as well as share CEM's expertise. The SC prepared a SWOT Analysis of this field trip comprised of input from its hands-on observations during their forest site visits.

Afterwards, at our request, Rob van der Weert, a specialist in Hydrology-Water Resources Management visited-Mangaia.. He was asked to look at the problem of water management and the possible impact of the pine tree plantations on the water supply.. He quantified the Steering Committee's earlier, SWOT-analysis, and determined that the pine trees most likely did impact on water availability to the streams. He made some recommendations to possibly improve the situation.

In this document you will find the report of Rob van der Weert, followed by the SWOT analysis of the CEM Steering Committee.

We hope that it will be of use to field activities, management and local communities that we have interacted with, and to ourselves as a background documents for our (potential) CEM partners in the Oceania region.

IMPACT OF FOREST PLANTATIONS ON WATER RESOURCES AND EROSION ON THE ISLAND OF MANGAIA (COOK ISLANDS)



Rob van der Weert



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EXECUTIVE SUMMARY

The major concern of a larger part of Mangaia island's population is the water supply. Most inhabitants attribute the decline of river flows experienced over the years to the afforestation programme undertaken in the 1980s to control the severe erosion.

The larger part of this report is focussed on the impacts of the afforestation with *Pinus caribaea* on the river flows. Some attention is also given to options to improve the water supply conditions.

IMPACT OF THE FOREST PLANTATIONS

A trend analysis of rainfall data of Mangaia for the period 1914 – 2014 was carried out to determine if the declining river flows might be due to decreasing rainfall. This analysis showed no significant trend in annual rainfall over the 100-year period.

The pine forest plantation is likely to have caused a reduction of river flows in comparison with the ferns and the pineapple plantations which were covering the hills before. The major reason for the reduction in flow is the higher evapotranspiration of the pine forest. The evapotranspiration of ferns is much less because of the small rooting depth and corresponding low amount of soil moisture available for transpiration while the evapotranspiration of pineapple plantations is much less because of the low potential evapotranspiration rate.

Based on the available information, combined with a “best guess” of the potential evapotranspiration of ferns, it is concluded that the plantations of *Pinus caribaea* resulted in an average reduction of the river flow of some 30%. However in terms of percentage the reductions in the dry seasons are highest and in the order of 60 to 80%.

In comparison with pineapple plantations, which have a low potential evapotranspiration rate the reduction in average river flow is likely in the order of 60%.

The surface runoff of pineapple plantations is by far the highest, which explains the high rates of erosion. The infiltration of rainwater is highest under the pine forest but most is withdrawn by the root system to cover the evapotranspiration demand. As a result the groundwater recharge and groundwater outflow under pine trees is lower than under ferns or pineapple.

As a consequence of less flow in the rivers there also is less water available for the taro fields. However, it is not clear whether many taro fields are under fallow because there is less water available (due to less river flow and increased abstractions for water supply) or because of a declining population. Considering the reduced efforts to maintain the taro irrigation system it seems that the combination of both factors is a likely explanation.

With respect to erosion control it is concluded that the afforestation programme has been very successful. However, there appears a strong need for forest management to select pine or *Acacia* trees for cutting and possible replanting with trees that have a higher economic value. The number of trees to be cut obviously is determined by the demand for wood, not only on Mangaia but possibly also Rarotonga.

The use of chemical preservatives for the impregnation of the wood to increase its durability and resistance from being destroyed by insects or fungi should be avoided at all cost because of the waste problem and the risks to the environment.

WATER SUPPLY

Based on reports on Mangaia's domestic water supply (Falkland, 2000) a total demand of 330,000 litre per day is projected. This demand seems on the high side considering the population projections and the assumed per capita demands.

Based on a simple water balance of Mangaia, it is estimated that the total amount of fresh water flowing into the sea is the order of 50 million cubic meter per year which is about 400 times the above projected demand. This gives a very rough idea of water availability versus demand. The freshwater outflow may be important for the lagoon ecosystems at some places.

There is an urgent need to monitor river flows and water levels. Although a V-notch measuring device was placed in one of the streams together with a data recorder, no discharge data could be traced. Also the observation of groundwater levels should start as soon as possible.

Water supply from boreholes drilled near the outer Makatea wall might be a feasible alternative to the proposals made by Falkland (2000). Here, at some distance away from the coastline, the water flowing to the sea may still be fresh. There is likely more water available of better quality compared to the gallery system at the inner Makatea wall adjacent to the swamp areas. A disadvantage is that some deeper drillings will have to be carried out. Furthermore, because yields may vary substantially at short distances, more drillings may have to be carried out before a suitable well is struck.

It is recommended that the Mangaia Island Government seeks funds for a drilling project including drilling equipment and an experienced hydro-geologist.

1 INTRODUCTION

In October 2014, the Commission on Ecosystem Management (CEM) of the International Union for Conservation of Nature (IUCN) held their steering committee meeting in Rarotonga. The regional chair for Oceania, Kelvin Passfield, arranged for the committee members to travel to Mangaia for a field trip. The purpose was to put their collective expertise together to look at the impacts of the 900 ha pine plantation on the water supply, as this was a concern for the people of Mangaia. The committee gave some opinions, but the Chair of the CEM, Piet Wit thought that the best thing to do was to get an expert hydrologist to visit the island to provide a more technical perspective on the forest/water interaction. He subsequently arranged for the CEM to cover the costs to send a hydrologist to Mangaia to undertake this study. This field trip was from November 29 until December 10. One full week was spent on Mangaia. The days on Rarotonga were mainly spent on discussions with a number of resource persons and on data collection.

Before the tree planting started in the upper part of the island the hills were mainly covered by ferns and later on by pineapple plantations. Especially the intensive pineapple cultivation led to severe erosion in the early 1980s. The problem was amongst others aggravated by ploughing perpendicular to the contour lines and repeated fires of ferns on sloping areas, often triggered by the burning of plant residues in the pineapple plantations. It is not clear how much area was exactly under pineapple plantation at its peak. From information collected from different sources it is concluded that a larger part of the hill area was under pineapple plantations, except for areas that were too steep for mechanical plowing.

To control the erosion a 10-year afforestation programme (1984–1994) was started with financial support from the New Zealand Official Development Assistance (NZODA). Plantation forests mainly made up of pine (*Pinus caribaea*) and to a lesser extent also *Eucalyptus sp.* and *Acacia sp.* were planted. The afforestation programme also covered the steeper slopes where ferns were growing.

With respect to erosion control the forestry project is considered very successful. Hardly any signs of erosion were observed during the field trips apart from a few places with erosion caused by road cuts.

The major concern of a larger part of the population is the water supply. Most of the population attributes the decline of river flows over the years to the forest plantations. This is also expressed as such in the Puna Plans for the period 2014 – 2018 where water supply has the highest priority (Anon, 2014).

The larger part of this report is focussed on the impacts of the forest plantations on the river flows in comparison with areas where ferns were growing or pineapples were cultivated. Apart from that aspect also some attention is given to options to improve the domestic water supply conditions.

2 APPROACH

The following activities were carried out in relation to the short mission.

2.1 Literature collection and review

Before the mission started a literature review was carried out with respect to impacts of forestation and deforestation on the water resources in climatic conditions comparable to Mangaia. Particular attention was paid to evapotranspiration of *Pinus caribaea* and an internet search yielded a number of relevant publications.

In addition other literature was collected about Mangaia, including reports on water supply, geology, taro irrigation systems, etc.

2.2 Data collection

2.2.1 Rainfall data

Monthly rainfall data observed on Mangaia were collected for the period 2014 – present. Most of this time series were complete. The data were obtained from the rain gauges at the Eneora school and the Telecom station.



Rain gauge at school Eneora

2.2.2 Meteorological data

The following average monthly meteorological data, observed at the Mangaia meteorological station during the 15-year period 1977 – 1992 were collected:

- Minimum temperature (°C)
- Maximum temperature (°C)
- Relative Humidity (%)
- Sunshine hours (hrs/month)
- Wind speed (km/day)

2.2.3 Discharge data

Unfortunately, no discharge data could be made available for Mangaia although reportedly a V-notch measuring device has been installed in the past and water level data were recorded and stored on a data logger (Facon, 1990).

2.3 Review of maps

The following maps were reviewed:

- Topographic map 1:15,000
- Satellite image map

2.4 Discussions

At various instances discussions were held with resource people in various fields such as forestry, agriculture, water supply, environment, etc.

On the first day of the field visit discussions were held about the purpose of the field visit and available information. Staff from various departments participated.

On the last day of the field visit a brief presentation was given about the tentative conclusions of the field visit. This presentation and following discussions took place during the weekly meeting of staff from the various island departments and the mayor.

2.5 Field visits

During daily field trips all parts of the islands were visited. The main focus was on the hilly area covered with trees, the various streams coming down from the hills and the wetlands at the foothills where most of the agriculture is concentrated, including the important taro cultivation.

Outside this area a strongly karstified limestone wall (Makatea) is located which may be of specific interest for possible future drinking water supply, evidenced by springs surfacing at the beach.

During the field trips the salinity of various sources was measured using an EC-meter.

2.6 Analyses and report writing

Most of the time not spent in the field was used to review literature, to discuss the various issues related to forest and water supply, and report writing. For the hydrological analysis use was made of RAINRUN rainfall-runoff simulation model (Van der Weert, 1994).

3 BRIEF DESCRIPTION OF MANGAIA

3.1 Location and size

Mangaia is part of the Southern Cook islands and located at Latitude 21.9 South and Longitude 157.9 West. The distance to Rarotonga, the main island located north-west of Mangaia is about 200 km. A map of the island is shown in Figure 1 (source: Waterhouse and Petty, 1986). The size of the island is 51.8 km². The capital is the village of Oneroa on the west coast.

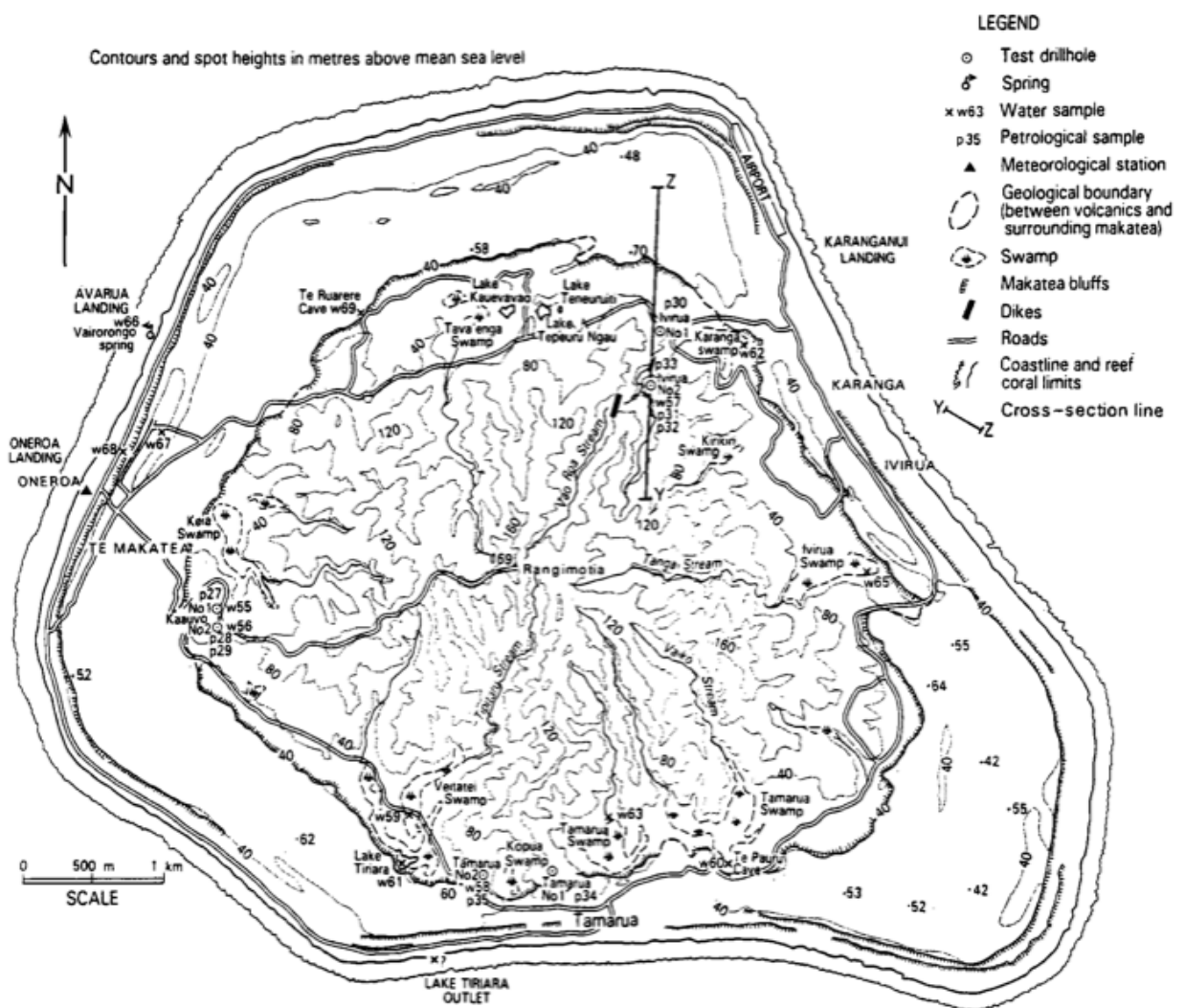


Figure 1 Map of Mangaia island

3.2 Geology

Mangaia consists of a low central plateau at Rangimotia from where rivers are flowing down in a radial pattern each ending in swampy depressions at the foot of completely encircling near-vertical wall of strongly karstified coralline limestone up to 60 m high (makatea). The swampy depressions, which can be up to 366 m wide are 6 m or less above sea level. They are drained to the sea through underground channels and caves in the makatea.

The volcanic rocks of Mangaia are deeply weathered. Outcrops are observed at the streams and at road cuttings. The volcanic core is mainly basalt. A few outcrops of fine-grained basalt occur on the southern and western slopes of the central hills.

The limestone forming the Makatea is dense, fine-grained, rarely showing details of structure. Much of it seems to be cemented coral sand. Analyses show that it is a remarkably pure calcareous limestone ($> 93\% \text{ CaCO}_3$). Coral sand forms a coastal belt, some 90 to 180 m wide surrounding the island, which supports coastal species such as much of the *Casuarina*, *Pandanus*, *Hibiscus* and other shrubs and trees. The sand strip is useful for road location and convenient for settlement, but unfortunately is not particularly fertile and is prone to damage in places by storm surge and large waves. The material consists of a few inches of mixed humus and coral sand and debris overlying un-cemented yellowish coral sand.



Road through Makatea

3.3 Land cover and land use

Before the large scale cultivation of pineapple started the hills of Mangaia were reportedly largely covered by ferns. Drawings made during the Cook expedition confirm the lack of forest on the island (see Figure 2). However, as described by Kirch (1996) there have been large changes in the island's vegetation in the past (see Figure 3). The most significant changes were initiated between 2500 and 1800 BP and were directly or indirectly associated with colonization by seafaring Polynesian peoples. These human-induced effects included major forest clearance, increased erosion of volcanic hillsides and alluvial deposition in valley bottoms, significant increases in charcoal influx, extinctions of endemic terrestrial species, and the introduction of exotic species.

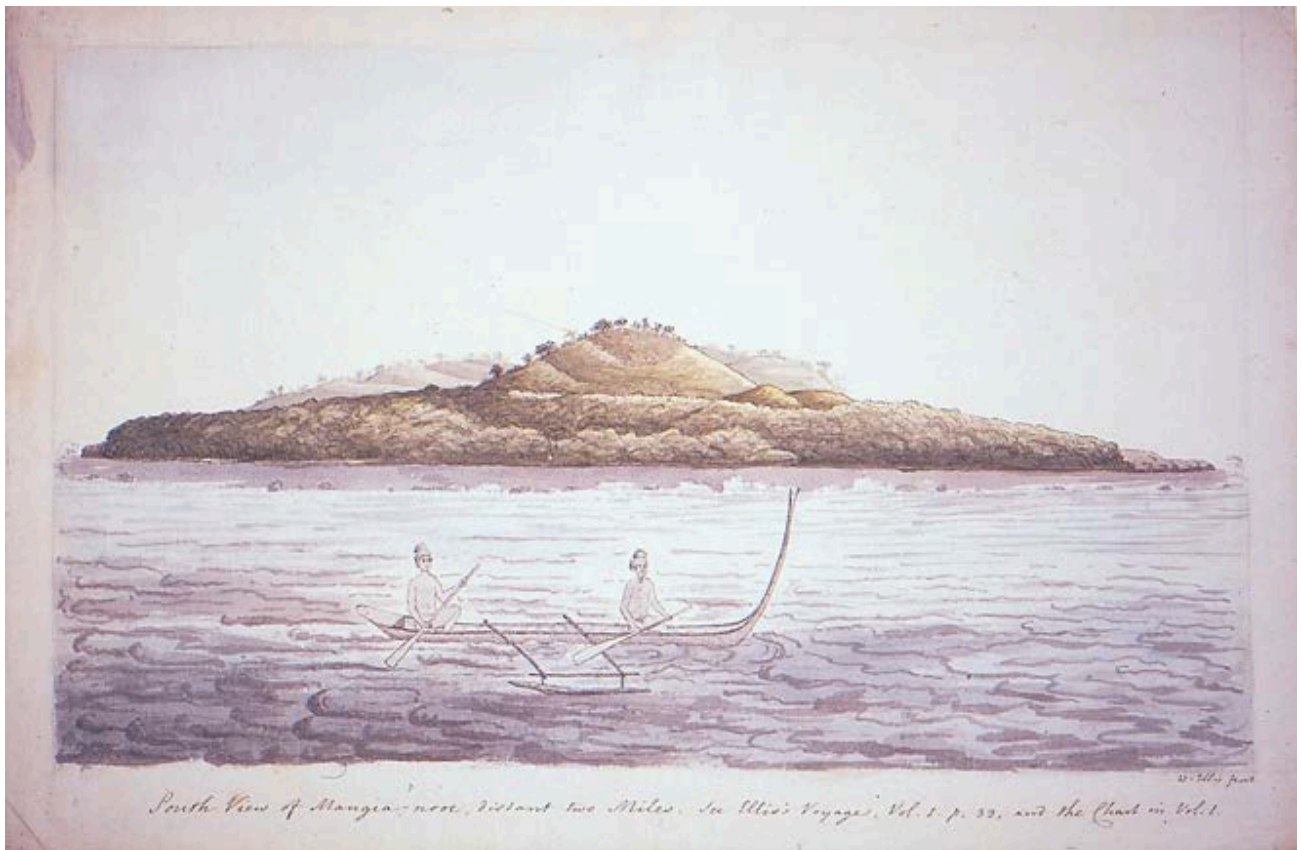


Figure 2 Drawing of Mangaia island during the Cook expedition

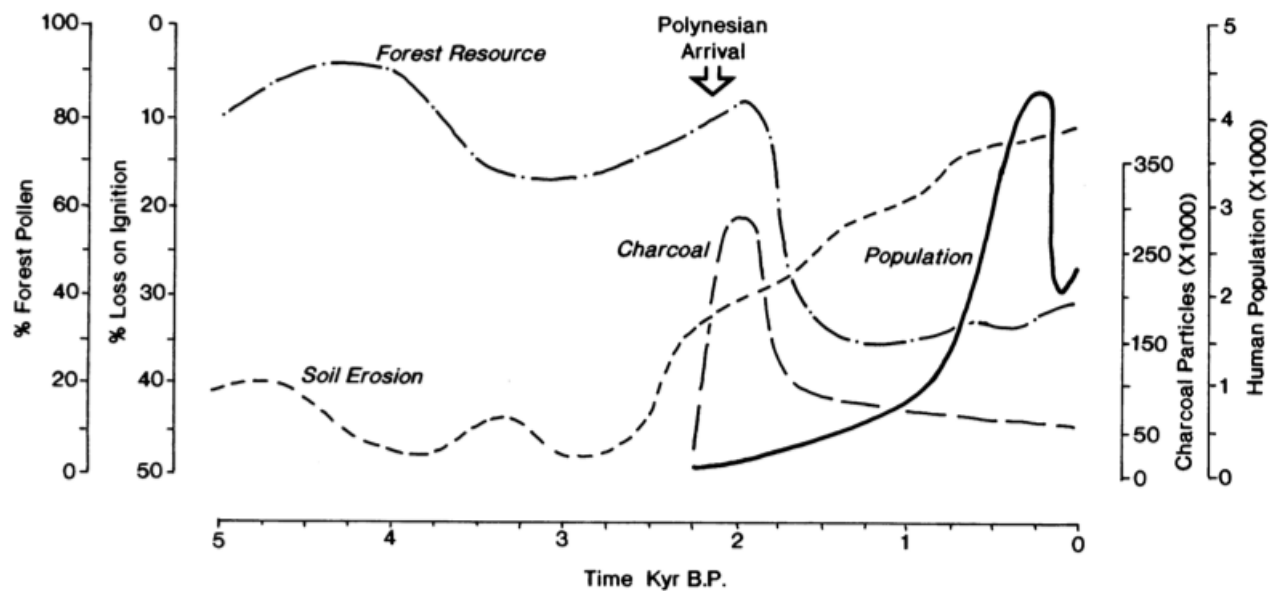
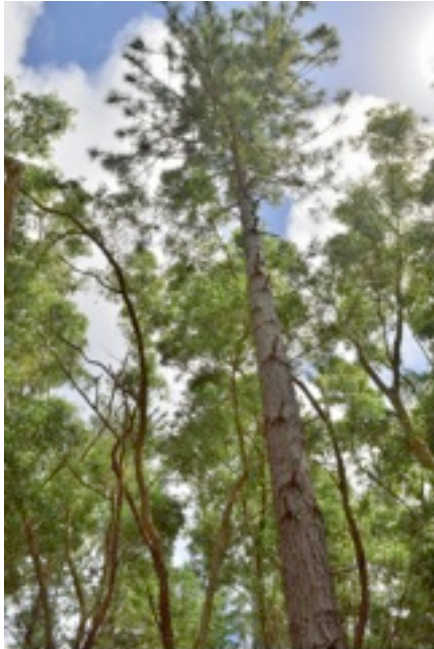


Figure 3 Diagram of major changes in forest resource, soil erosion, charcoal influx and human population over the past 5000 years (copied from Kirch, 1996)

Presently the island of Mangaia is covered with some 900 ha of forest plantation, mainly consisting of *Pinus caribaea*. The remaining area is covered by all kind of other tree species, shrubs and ferns in various degrees of density. Along the lower and flatter parts in the interior the various rivers end in wetlands where taro is cultivated.



Pinus caribaea

Some parts of the Makatea are not covered by vegetation. Reportedly, after the planting of trees in the 1980s also the vegetation in other areas increased, including on the Makatea.



3.4 Population

According to the diagram shown in Figure 3 the island population peaked at some 4000 to 4500, around the time that the Cook expedition visited the island. The census data from 1902 onwards show a drastic decrease in population, especially after 1971 (Figure 4). Following the trend the population in 2014 would probably be around 500 people.

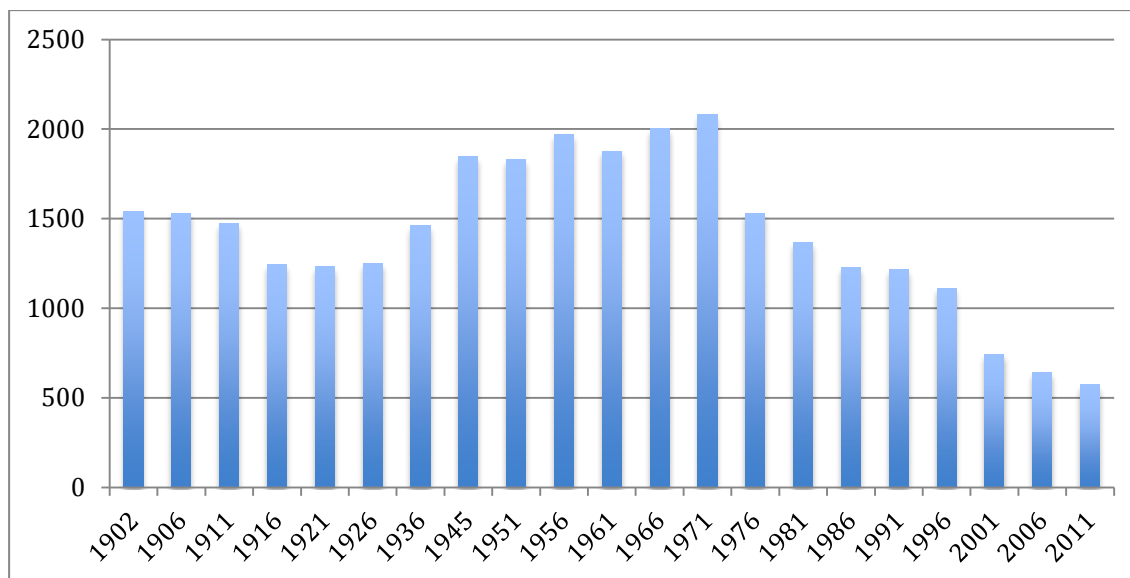


Figure 4 Census data Population Mangaia (source: <http://www.mfem.gov.ck>)

3.5 Economic activities

The Cook island government appears the biggest employer on Mangaia. Economic activities are mainly restricted to agriculture, fisheries and to a much lesser extend tourism. Partly because younger people are leaving the island to seek work or study overseas the agriculture sector is going down. This is illustrated by many taro fields that are left fallow and taro irrigation systems that are no longer maintained. Although there seems a great potential for tourist development this sector is hardly developed.



Taro field

4 HYDROLOGICAL CONDITIONS

4.1 Rainfall

Rainfall on the island has been measured at the school in Oneroa and at the Telecom office. The latter one, a tipping bucket recorder, reportedly transmits data to the meteorological office in Rarotonga. Apparently quite recently two new rain gauges were installed of the same tipping-bucket type, one on top of the island, at Rangimotia near the telecom antennas, and one near the church in Karanga. Both recording rain gauges are not connected to a data transmission system.

The average monthly rainfall is shown in Figure 5. It seems that the driest period lasts from June through September but even in this driest period the rainfall is on average in excess of 100 mm/month, which is generally not considered as very dry.

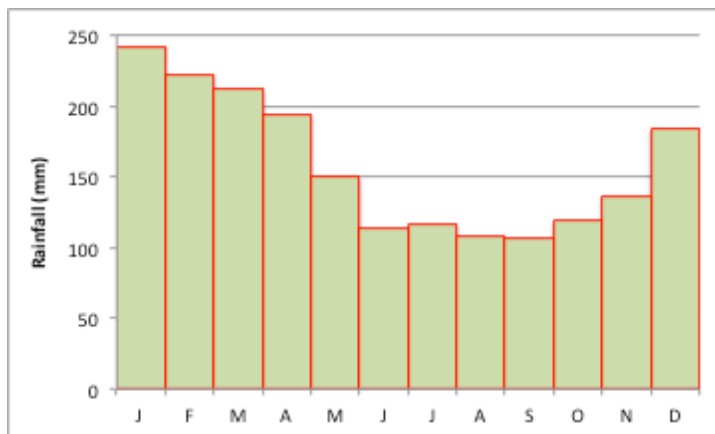


Figure 5 Average monthly rainfall in Mangaia

For the hydrological years¹ September through July the annual rainfall is shown in Figure 6. There are a number of gaps in the time series, caused by one or more missing monthly data.

The minimum, mean, and maximum annual rainfall are as follows:

- Minimum: 1001 mm/year
- Average: 1951 mm/year
- Maximum: 2920 mm/year

¹ A hydrological year is a term commonly used to describe a 12-month period which starts and ends in the driest period within a year in order to more directly relate rainfall to the resulting runoff in the same period

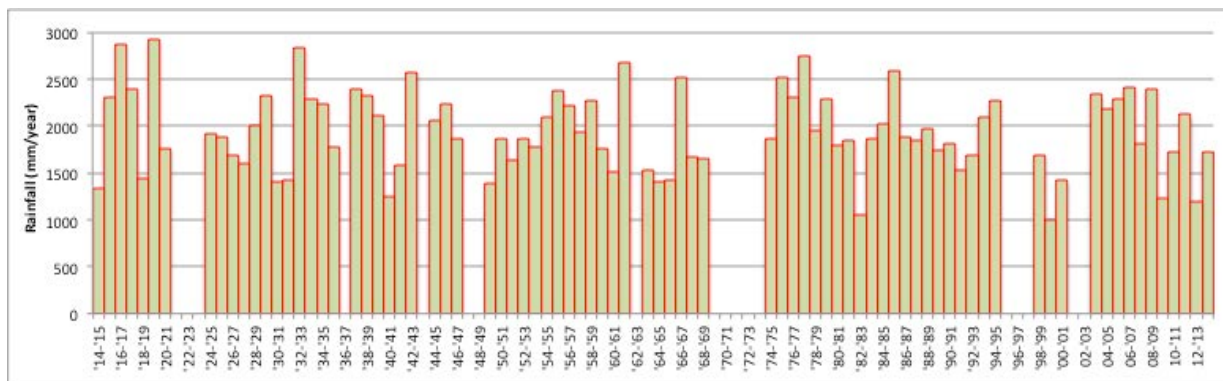


Figure 6 Rainfall for hydrological years for the period 1914-'15 till 2012-'13

To judge if the declining river flows might be due to decreasing rainfall over the years a trend analysis was carried out. This analysis showed no significant trend in annual rainfall.

Low rainfall amounts for durations of 1 up till 6 months and average return periods of 5 and 10 years are shown in Figure 7. It appears for example that on average once every 10 years a low rainfall during 2 months of only 44 mm occurs. However, this is certainly not an exceptional low value.

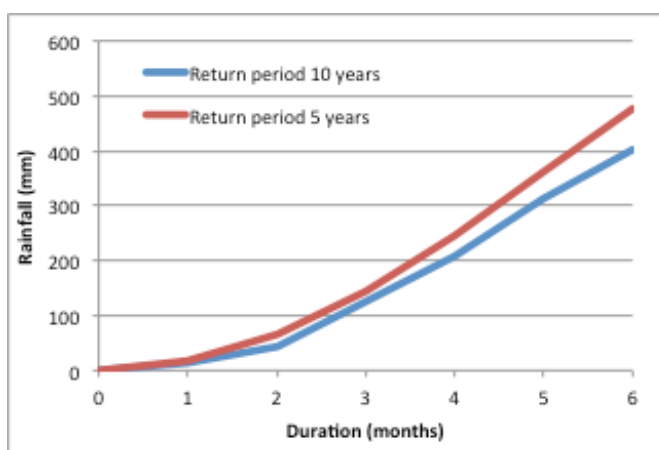


Figure 7 Rainfall during drought periods at return periods of 5 and 10 years.

4.2 Evapotranspiration

4.2.1 Potential evapotranspiration

Potential evapotranspiration of an area covered by a specific type of vegetation is the amount of water lost to the atmosphere when there is no shortage of water. The evaporation losses include:

- transpiration (the uptake of water by the roots of the vegetation and subsequent evaporation from the leaves through the stomata)
- evaporation from the soil (usually minor when the soil is fully covered by the vegetation)
- evaporation from rainfall intercepted by the vegetation

The potential evapotranspiration of a specific type of vegetation is determined by the meteorological conditions and by the aerodynamic and stomatal diffusion resistances of the vegetation type. It is common practice to relate the potential evapotranspiration of a specific vegetation type to the potential evapotranspiration of a so-called reference crop, which resembles an extensive surface of green grass of 12 cm in height:

$$E_{pot} = K_c \times ETo$$

where:

E_{pot} = potential evapotranspiration of a specific vegetation type (mm/month)

K_c = vegetation coefficient (-)

ETo = reference crop evapotranspiration (mm/month)

For more information on potential evapotranspiration and reference crop information reference is made to FAO (1998).

In Table 1 the average monthly meteorological data, collected at the Mangaia meteorological station during the 15-year period 1977–1992 are shown as obtained from the meteorological office in Rarotonga. Also shown are the short wave incoming radiation and ETo values computed from this data.

For a large number of agricultural crops K_c values are given by FAO (1998). Their use is mainly for the determinations of irrigation requirements. However the ETo values are also widely used for other hydrological applications such as rainfall-runoff modelling where K_c values are used as average vegetation coefficient to determine the potential (=maximum) evapotranspiration loss in a catchment. In such cases the K_c value is usually determined during the model calibration.

Table 1 Average monthly meteorological data and estimated ETo values

Monthly ETo Penman-Monteith - C:\CROPWAT\data\climate\Mangaia.PEM						
Country Cook Islands		Station Mangaia island				
Altitude 100 m.	Latitude 21.90 °S		Longitude 157.90 °W			
Month	Avg Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/month
January	25.4	87	440	4.4	17.5	112.36
February	26.0	84	421	5.3	18.3	112.23
March	26.2	89	407	6.0	17.9	109.43
April	24.8	85	587	4.1	13.1	94.74
May	23.5	90	557	4.0	11.1	69.45
June	21.9	86	465	4.1	10.2	67.86
July	21.2	88	507	4.7	11.3	66.98
August	21.1	84	517	5.2	13.6	85.54
September	21.8	77	429	4.9	15.4	107.48
October	22.3	82	499	5.2	17.6	112.42
November	23.8	81	374	5.3	18.7	119.70
December	24.6	83	517	4.8	18.3	123.76
Average	23.6	85	477	4.8	15.3	1181.96

For Pine trees there is some limited information. Only one publication based on research on the Fiji islands appeared quite relevant. The available literature on pine trees is briefly summarized below.

Netherlands

In the Netherlands a lysimeter experiment with *Pinus nigra austriaca* started as far back as 1941 (Warmerdam a.o., 2000). For the 22-year period 1976 – 1997 the average water consumption (=actual evapotranspiration, ETa) was 720 mm/year. For the same period the results of a similar lysimeter experiment in Germany gave a value of 580 mm/year where the average annual rainfall was some 50 mm/year less. These values are given only as background information since the meteorological conditions between The Netherlands or Germany and the Cook islands are very different.

Florida

Using a lysimeter the evapotranspiration losses of pine trees in North Florida were measured during a 2-year period (Rietkerk, 1985). During the first year the actual evapotranspiration ETa was 923 mm and during the second wetter year the ETa value reached 1098 mm/year. This value was reportedly close to the potential evapotranspiration value Epot of 1122 mm/year.

Fiji

A more recent interesting study was carried out with *Pinus caribaea* on Viti Levu, Fiji islands (Waterloo a.o.,1999) where wet and dry canopy evaporation from young and mature plantations of *Pinus caribaea* were determined using micro-meteorological and hydrological techniques. In this experiment high ETa values of 1926 and 1717 mm/year were measured for tree plots with stem densities of 825

and 621 per hectare, respectively. These values are considered very high by the authors. For pine forest at the larger catchment scale, with a stem density of 459 per hectare the annual ETa appeared 1301 mm.

The measurements on *Pinus caribaea* in Fiji obviously seem the most relevant for Mangaia. The pine forest at the catchment scale in Fiji, with a stem density of 459/ha comes closest to the Pine forest in Mangaia where the stem density reportedly is 400/ha.

Based on the meteorological data provided in the same publication (Waterloo a.o., 1999) the ETo value is estimated at about 1400 mm/year. Thus the ratio between the ETa value of *Pinus caribaea* and the ETo equals $1300/1400 = 0.93$. The Kc value is likely somewhat higher assuming some water shortages during the observation period and an arbitrarily Kc value of 1.0 is assumed for estimates in Mangaia.

For ferns no information could be traced on Kc value or actual evapotranspiration. For grass and alfalfa on the other hand much data is available and the best estimate is a Kc value of 1.0, similar to the Kc-value for *Pinus caribaea*. At first sight this may seem rather strange considering the large differences with respect to height and Leaf Area Index (LAI). However, from other examples Kc values of specific trees may even be lower than for alfalfa or grass. For example citrus has a Kc value of 0.75. For ferns a Kc value of 1.0 is assumed in the present study.

For pineapple a Kc value of 0.3 to 0.5 is given by FAO (1998).

4.2.2 Actual evapotranspiration

The more soil moisture is available in the root zone the longer the evapotranspiration will be at the potential rate. However after some 30 to 50% of the available soil moisture in the root zone is used the soil moisture tension increases and the vegetation reacts by a (partial) closure of the stomata to reduce the transpiration losses.

The rooting depth of *Pinus caribaea* can exceed 400 cm whereas the maximum rooting depth of Ferns can reach some 15 cm. The Fern roots are characterized by pseudo root system connecting the above ground ferns and small roots going down from the pseudo roots entering the soil. The organic layer on top of the soil consists of a loosely packed 10 cm thick layer of old pseudo roots and died fern leaves. For pineapple a rooting depth of 40 cm is assumed, based on information found in the literature (http://www.fao.org/nr/water/cropinfo_pineapple.html).

Based on the predominantly loamy soil types an amount of available soils moisture (between field capacity and permanent wilting point) of 20% by volume was assumed.

To estimate actual evapotranspiration and runoff use is made of a rainfall-runoff model.

4.2.3 Rainfall – runoff modelling

To judge the impact of forestation on the river flows on Mangaia a d version of the RAINRUN model (Van der Weert, 1994) was used. The model was especially developed to estimate the impacts of deforestation on runoff characteristics. The model inputs include time series of rainfall and ETo values. A full description of the model is beyond the scope of this report.

One of the simplifications applied is that evaporation of rainfall intercepted by the canopy is not separately dealt with in view of the lack of data. Instead all rainfall reaches the ground surface in the model from where part is transformed into surface runoff while the remaining part infiltrates into the soil and adds to the soil moisture content from where it is available for evapotranspiration. Any soil moisture in excess of the soil moisture capacity will directly recharge the groundwater. The errors resulting from these simplifications are considered relatively minor, in view of the fact that the main interest of the simulations is to determine the difference in runoff between different vegetation types and justified in the lack of observed runoff data based on which the model parameters could be calibrated.

Based on available information and the literature review discussed above, a number of model parameter values were selected to estimate the difference in actual evapotranspiration and runoff between *Pinus caribaea*, ferns, and pineapples. The adopted parameter values are given in Table 2. Also included are the surface runoff fractions, which are estimated, based on the observed field conditions and experience.

Table 2 Selected parameter values

Parameter	<i>Pinus caribaea</i>	Ferns	Pineapple
Surface runoff fraction of rainfall (-)	0.05	0.10	0.25
Effective rooting depth (cm)	350	10	40
Available soil moisture capacity (mm) ¹⁾	700	20	80
Vegetation coefficient Kc (-)	1.0	1.0	0.4

1) Soil moisture held between field capacity and permanent wilting point in loamy soils assumed 20%

One might argue that the rooting depth of *Pinus caribaea* could be less when restricted by rocky substrata. However, even at half the depth assumed above the total runoff would only increase marginally.

From the simulations it appears that the runoff decreases with about 300 mm/year when the fern vegetation is replaced by *Pinus caribaea*. In case of the pineapple plantations the decrease is as large as 500 mm/year. These reductions in average river flow correspond to some 28 and 64% for ferns and pineapple plantations, respectively.

In Figure 8 the comparison is shown for the three vegetation types of how the average annual rainfall is distributed over the different water balance components of surface runoff, groundwater runoff and actual evapotranspiration.

The surface runoff of pineapple plantations is by far the highest, which explains the high rates of erosion. The infiltration of rainwater is highest under the pine forest but most of this water is withdrawn by the root system to cover the evapotranspiration demand. As a result the groundwater recharge and groundwater outflow under pine trees is lower than under ferns or pineapple although the infiltration was substantially higher in case of the pine forest.

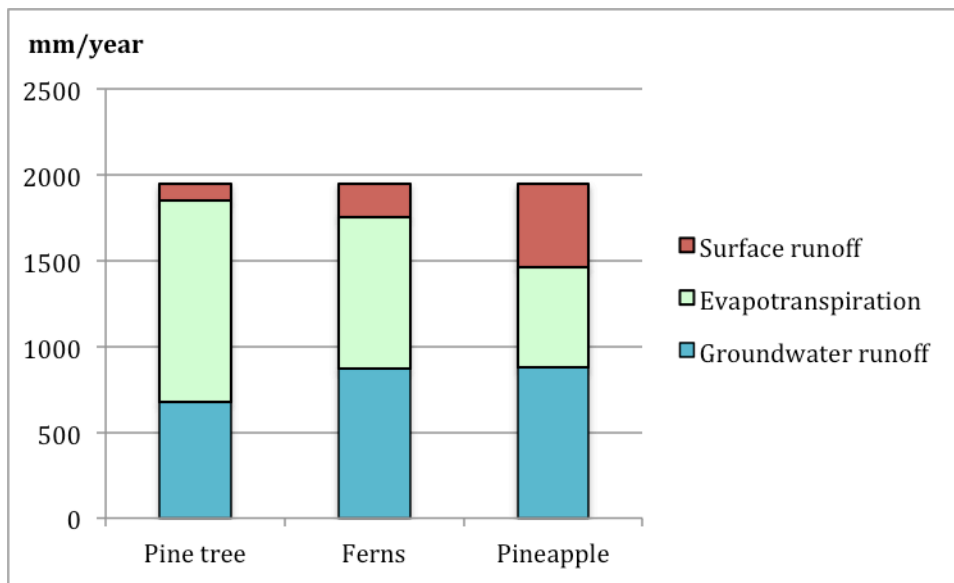


Figure 8 Comparison of evapotranspiration and runoff for the different vegetation types

The groundwater system in rainfall-runoff models is usually considered as a linear reservoir whereby the outflow is proportional to the amount of groundwater in storage:

$$O = \alpha \times S$$

where:

O = Outflow (mm/day)

α = reaction coefficient (day^{-1})

S = groundwater storage (mm)

For different groundwater reaction coefficients the impact of *Pinus caribaea* replacing the fern vegetation was estimated on the flows that occur at different percentile values. Results are shown in Table 3.

Table 3 Impact of *Pinus caribaea* replacing ferns on the river flows

(at different percentile values and groundwater reaction coefficients)

Flow Percentile P (x<X)	Flow reduction at different groundwater reaction coefficients		
	$\alpha = 0.3^{1)}$	$\alpha = 0.5^{1)}$	$\alpha = 0.7^{1)}$
0.05	72%	77%	78%
0.10	63%	74%	80%
0.20	52%	63%	72%
0.30	42%	52%	63%
0.40	36%	43%	51%
0.50	31%	34%	37%
0.60	25%	26%	26%
0.70	23%	21%	22%
0.80	18%	19%	18%
0.90	14%	12%	13%
0.95	12%	9%	10%

¹⁾ Daily values converted to monthly values

Percentage wise it appears that the impact of *Pinus caribaea* is very pronounced in the drier periods (about 60 to 80% less flow at the 10% percentile low flows). At the higher percentile of 90% the flow reduction is in the order of 12 to 14%.

For a groundwater reaction coefficient of 0.5 the time series of monthly flows is shown for the 3 vegetation types in Figure 9.

For the areas covered by ferns and pineapple it seems that the rivers never completely dry up. This is in contrast with the area planted with *Pinus caribaea* where there are a number of occasions that the rivers dry up.

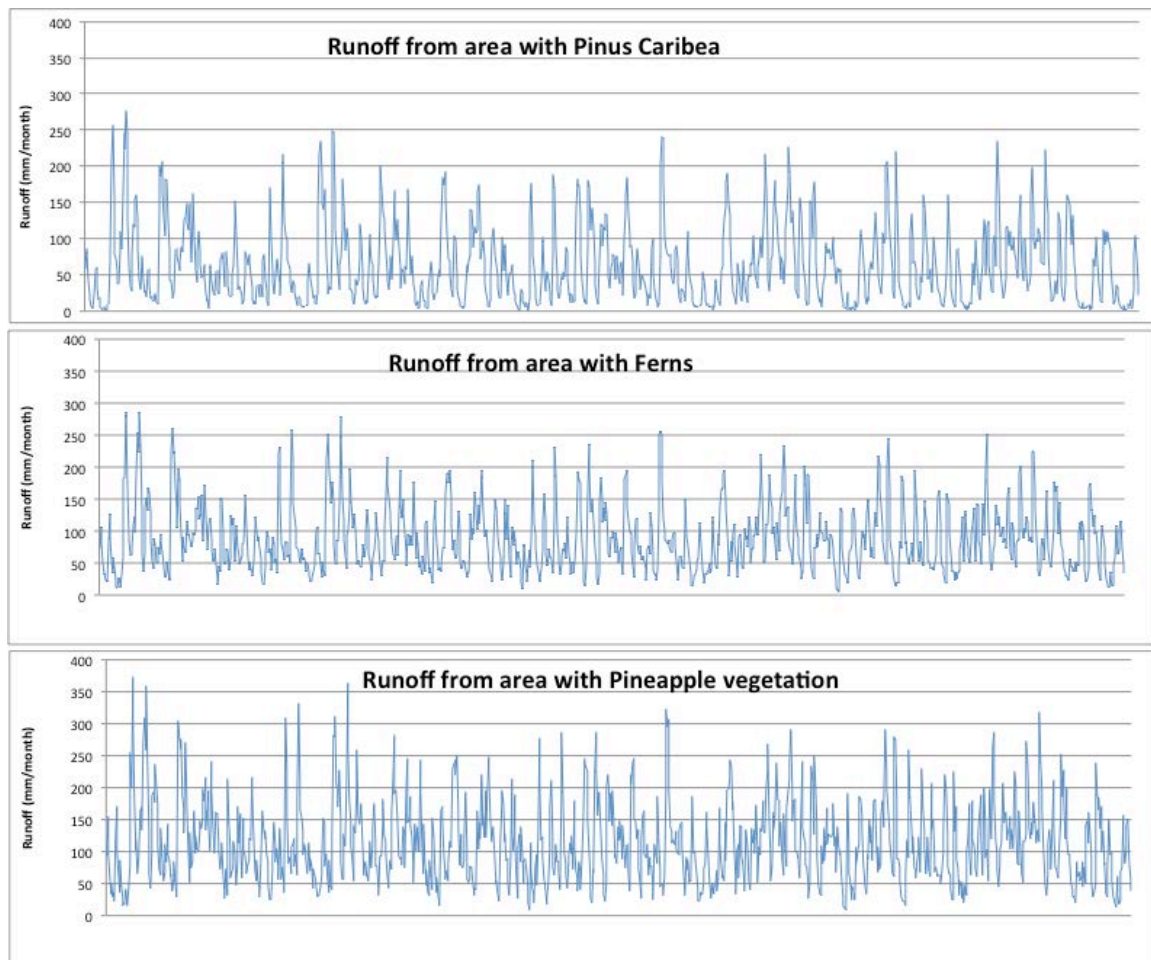


Figure 9 Simulated runoff from areas covered with *Pinus caribaea* , ferns and pineapple

5 WATER SUPPLY

5.1 Water Stress Indicator

According to the Falkenmark Water Stress Indicator a country or region is said to experience "water stress" when renewable annual water resources fall below 1700 cubic metres per person per year. Although a large part of the water resources on Mangaia cannot be reached easily, especially in the Makatea area, there certainly is not a water stress condition on the island.

5.2 Past situation

Before, water was pumped from 4 boreholes, drilled with NZAID funding. Two were located in Keia and the other two in Karanga and Tamarua. Diesel pumps were used to pump the water to storage tanks from where the water was distributed to the villages by gravity. After some problems with the pumps caused by wear and tear and increasing maintenance cost the diesel pumps were replaced by windmill pumps. Reportedly there were more problems experienced with the pumps and in 1987 the windmills were dismantled and shipped to Mauke. The boreholes were no longer used and replaced by river intakes, which at present still are in operation.

5.3 Present situation

For drinking water almost every household on Mangaia has a 6000 litre tank which collects rainwater falling on the roof of the house. There are not many complaints about this system although the quality of some tanks seems less than desirable in view of cracks on the sides of the tanks.

Water for other purposes, such as for showers, toilets, laundry, etc. is diverted from four river intakes in the interior and from one well near the coast. Three of the four river intakes supply water by gravity to the villages. The water from the other one is pumped to a storage tank on the Makatea from where it is distributed by gravity. Water from the coastal well is also pumped to a tank on the Makatea.

Especially the diverted river flows vary throughout the year. The flow from the well at the coast (Vairorongo spring), which is fed by drainage water from the interior plus recharge from the Makatea area, varies much less. This water flows through tunnels in the strongly karstified Makatea. The water pumped from this source is slightly brackish. An EC measurement during this fieldtrip showed a salinity of 1300 ppm.

In addition there are also some 15 larger concrete tanks for the collection of rainwater for communal use.



Intake Karonga (left) and pump at Vairoronga spring (right)

Major problems in the present water supply system are:

- variability in diverted river flows and shortages in dry periods
- competition with water supply to taro areas
- poor water quality due to river-intake of water with high sediment load (inadequate filter system at the intakes)
- salinity from the coastal well

5.4 Options for improvement

In the reports prepared by Falkland a number of possible options are discussed to improve the water supply situation (Falkland, 2000 and 2003). These include improvement of the present river-intakes, development of galleries near the inner Makatea wall and swamp areas, re-use of boreholes that are presently no longer used, and extension of the rainwater collection system.

The water demand projected by Falkland (2000) was based on a daily per capita demand of 150 lcd (litre per capita per day), which seems on the high side. In The Netherlands for example the average consumption is 110 -120 lcd.

For a “design” population for Mangaia of 1400 people and including an additional demand for schools, offices, churches, health clinic, etc. and assumed system losses of 30%, a total demand of some 330,000 litre per day was projected. Such demand will put a heavy load on the system.

Based on a simple water balance of Mangaia it is estimated that the total amount of fresh water lost to the sea is in the order of 50 million cubic meter per year which is about 400 times the above projected demand. It is realised that such figure is rather meaningless but at least it gives a very rough idea of water availability versus demand.



Outflow to the sea

Apart from the above proposals it seems that borehole drillings near the outer makatea wall also might be a feasible option. Here, at some distance further away from the coast, the mixing with seawater may not occur yet and the water may be of good quality. Hence, compared with the gallery system at the inner makatea wall adjacent to the swamp areas there likely is more water available of better quality. A disadvantage is that some deeper drillings have to be carried out. Furthermore, because yields may vary substantially at short distance due to the nature of the karstified limestone more drillings may be needed before a suitable well may be struck.

Already an attempt was made to drill at a slightly higher elevation near the existing abstraction well at the coast, near the Avarua landing. However, this attempt was not successful because the available drilling equipment on the island could not drill beyond a depth of about 4 m.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 Impacts of the forest plantations

Although there is a lack of data on water consumption of especially ferns it is concluded that the pine forest plantation likely caused a reduction of river flows in comparison with the ferns which were covering the hills before. The major reason for the reduction in flow is the large difference in rooting depths between pine forest and ferns and the corresponding difference in soil moisture available for abstraction and transpiration. Hence, the transpiration of the pine forest may continue at its potential rate much longer whereas the ferns will reduce the transpiration much earlier by stomata closure as a reaction to rapidly increasing soil moisture tension.

In comparison with pineapple plantations the reduction in river flow is even more outspoken because the evapotranspiration losses of pineapple are low, even in comparison with ferns.

As a consequence of less flow in the rivers there also is less water available for the taro fields. However, it is not sure whether many taro fields are under fallow because there is less water available (due to less river flow and abstractions for water supply) or because of a declining population. Considering the reduced efforts to maintain the taro irrigation system it seems that the combination of both factors is a likely explanation.

A very positive impact of the forest plantations on Mangaia is that soil erosion is reduced substantially, especially on areas formerly used for pineapple plantations.

6.2 RECOMMENDATIONS

6.2.1 Monitoring

There is an urgent need to monitor river flows. Although a V-notch measuring device was placed in one of the streams together with a data recorder, no observed discharges could be traced, hampering proper design and development of water supply and irrigation systems (see a.o. Facon, 1990). Also the observation of groundwater levels should start as soon as possible.

6.2.2 Lysimeter experiment

In the absence of data on potential evapotranspiration of ferns it is recommended to start a lysimeter experiment for a period of say 2 years. This could reveal a more accurate evapotranspiration value than assumed in the present study. The experiment is proposed to be guided by a student interested in hydrology.

6.2.3 Forest management

Removing the entire forest area or a substantial part of the forest area to increase water availability, as suggested by some, seems not realistic. In the first place because of the terrain conditions, the related high cost in equipment needed (cable ways?), the transportation cost, and the labour requirement.

Under the present conditions there seems a strong need for forest management to select pine or *Acacia* trees for cutting and possible replanting with trees that have a higher economic value. The number of trees to be cut is obviously determined by the demand for wood, not only on Mangaia but possibly also Rarotonga. The use of chemical preservatives for the impregnation of the wood to increase its durability and resistance from being destroyed by insects or fungi should be avoided at all cost because of the waste problem and the risks to the environment.



Saw mill

Considering the amount of fresh water lost to the sea through tunnels and cavities in the strongly karstified Makatea limestone it seems that drilling near the outer Makatea wall may yield good sources for water supply. It is therefor proposed to find the funds for a drilling project including drilling equipment and an experienced hydro-geologist.

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Swot Analysis CEM Steering Committee

Strengths

- No hurry to take any decisions, there is no acute water- or forest related problem
- Erosion control by plantation of forests very successful
- Large standing volume of high value pine
- Other trees – sandalwood (high value), *Casuarina* and other species already present
- Enough water to cover the needs of 500 residents and the future eco-tourists



Weaknesses

- Waste management on the island. This must be isolated!
- Forest fire risk is real. Fire-control measures needed.
- First indications of diseases within forest are visible
- There seems to be a lot of water, but efficiencies of water use and water- harvesting can be much improved
- Unclear what the willingness of people on island will be to really engage (importance of ownership of process)
- No Government funding to support a forestry manager, so would need to seek external project funding



Opportunities

Forestry related:

- There should be a forestry manager
 - o Silvicultural treatments and management
 - o Fire control
 - o Appropriate alternative trees or crops to replace any removed trees
- Business plan needed + feasibility study.
 - o Ecosystem management does not only look at trees and soils, but also at institutions managing these.
 - o What is being monitored already and what not? Predictions taking into account climate change. The current situation is different from 30 years ago, because of e.g. the variation in rainfall.
 - o Links to existing development plans
 - o Explore different scenario's
 - o forest/silvicultural management
 - Baselines: e.g. scale and scope of existing data; assess standing volume;
 - operational plans: e.g. thinning of forest, rotational harvesting;
 - o governance and ownership:
 - o Potential of harvesting and selling non-timber forest products (pine needles, local medicines)
 - o Important to link external expertise with local capacity building; potential role of interns; students to assist with these studies preferably come from the Cook Islands or the Pacific region.
 - o A field station might be set up to provide a continuous presence of researchers
 - o Explore the value chain – markets (where, what); how to get to the market; who to be involved
 - o Cost benefit analysis of different options; with a focus on sustainable forest management
 - o If future exploitation of forests requires equipment – need to explore how best to finance (loan, interest, grant)
 - o Cultural values must have a place in business plan, as they erode
 - o to identify the potential for integration of forest opportunities into the broader economic development of the island
- Other tree species could be planted – sandalwood (high value), *Casuarina* can be used for boats etc.
- Wood might be used for 'high value, low volume products'. Locally processed wood e.g. for the design market



Other livelihood aspects

- Developing biodiversity conservation- and management aspects within the current UNDP-GEF project – as potential opportunities for investment.
- A real potential for eco-tourism exist: walking trips to discover the island and its surrounding lagoon/reef systems; discovery of cultural values
- Develop organic farming

Threats

- Open spaces provide opportunities for invasive species. When thinning or cutting the forest, high chances invasive species coming in. The Australian Acacia species planted for erosion control already acts as such. Invasive vines are also a threat.
- When thinning or cutting the forest high chance of water flushing away into the ocean and erosion to return
- Perception of effects on water based on emotions, not necessarily on facts. Issue has become political which does not necessarily help to find a solution.
- The volume of harvestable timber may be large enough to attract a foreign merchant to extract all the timber and ship it off. This will lead to a loss of opportunities related to the sustainable harvest and local processing of the timber and is likely to aggravate the situation around water- and land management (erosion!)
- Goats often create problems on islands for local biodiversity. No complaints (yet) in Mangaia. Wild pigs also pose a threat to agriculture



Other issues to note.

- o In order to encourage emigrated Mangaia citizens to return, it is important to understand what salary-structure will be needed to make that happen
- o Need to gain understanding of perceived water issues, improved understanding of overall water management on island e.g. move from diesel powered water pumps to more sustainable energy, e.g. solar panels
- o Community meetings/workshops – to really gain local interest and ownership. Local communities must remain in the driver seat!
- o Understanding present and potential future institutions for management of natural resources, of the forests, trees – ownership, rights/responsibilities. Role and importance of the 6 Punas (or districts) – who have primary responsibility for their lands (decentralized governance)
- o Forest, business and community participation needs to be integrated

Waste management issues.

- o Glass crushers could be used to dispose of the many empty bottles and to fill potholes with
- o Public education needed on recycling, and reducing waste coming into the island